OPTIMISATION OF A KART CHASSIS

This article is a theoretical treatment of the design applied to the development of a kart racing chassis, and was the basis of an undergraduate final year project undertaken within the Department of Manufacturing Systems Engineering at the Royal Melbourne Institute of Technology (RMIT) Melbourne, Australia. The aim is to improve the design process using the finite element method. It is proposed to optimise chassis performance using this technique, as significant variability exists in current testing procedures. The following is a summary of how the stiffness and performance of a chassis can be predicted by combining laws of physics with the finite element method.

There are several advantages when using structural analysis or computer simulation software. Firstly, they can predict to a certain degree of accuracy how a component will perform under different conditions, in this case a kart chassis. Secondly, by designing a chassis in a three dimensional CAD package, several variations of a design can be analysed in a day. This allows a designer to experiment with different variations on chassis geometry without producing a chassis, therefore research and development costs are reduced, and a kart design representing something closer to the optimal solution. Thirdly, variability is eliminated in current test procedures, thereby eradicating testing of prototype chassis up until a designer is confident with how the chassis should perform under varying dynamic conditions. Most karters can appreciate how difficult it is to maintain consistent lap times in day to day practice, and with the exception of the driver, the largest variability is the characteristics of the tyres. Tyres are influenced by several factors governing their road holding performance thus altering the dynamics of the chassis.

Photo: Keith Lock

Figure 1. Kart decelerating and turning into a corner. As the weight transfers to the front left wheel it causes the front left corner to flex upwards. Since the chassis is rigid, the diagonally opposite wheel lifts

CHASSIS FLEX

The primary function of vehicle chassis is to join all suspension mounting points, and distribute the load from each mounting point to all other mounting points. The essential difference between kart and car chassis is in the suspension. Karting simplicity demands an unsprung chassis, but while the kart may not have suspension, it is still subjected to the same forces effecting any automobile. Kart chassis design must take these forces into account. The requirements are for something rigid in bending and torsion moments, and without excessive sag or twist.

When people talk of karts not having suspension they are wrong. Karts have a form of springing and shock absorbing, but instead of being recognisable individual units, it is part of the chassis and shows itself as frame flex. As the flex moves back down the frame, members having different main functions can be used to impart more and more restraint to flex continuing.

The placing of cross members drastically alters how much the chassis will flex, and one is usually placed about half way back in the frame and provides the first restriction to further flex. The undertray is left loose so the frame isn't restricted and remains flexible, thus localising the stresses to the chassis/tubing. When the flexure has reached the seat and the outsweeping of the frame, little opportunity for flex is left, so by the time it gets to the engine mount and rear axle it is finally fully restricted.

The stiffness of a chassis can be measured in several directions simulating different dynamic conditions. For the purpose of this article, only torsional stiffness is reviewed. The torsional stiffness of a chassis is important, as this determines how much a kart chassis flexes during braking into a corner. The relationship of stiffness is linear, i.e. you apply a force and get a displacement, so by doubling the force the displacement increases by the equivalent margin. In brief, stresses too are linear. Every material has a critical stress (yield strength), once this critical stress has been reached the material becomes permanently deformed from the original design. On some older karts it is possible to see a wheel slightly raised, this is most likely caused by driving in the same direction around similar corners, thus localising the stressing on the frame at the same point. An example of permanent deformation is if a piece of metal is bent and the critical stress is reached, the metal becomes permanently deformed and the material will not return to its former position.

LOAD TRANSFER

The handling of a kart is influenced by a large number of factors. These include weight distribution, centre of gravity height, tyres, wheelbase and track dimensions, polar moment of inertia, and even the amount of power being applied to the driving wheels. Because of limitations set by karting legislation, the design scope is predetermined to quite tight limits.

The question arose, how can realistic reaction forces be introduced into the simulation that are comparable to forces found during racing. After a little thinking, the answer is by deriving an equation of

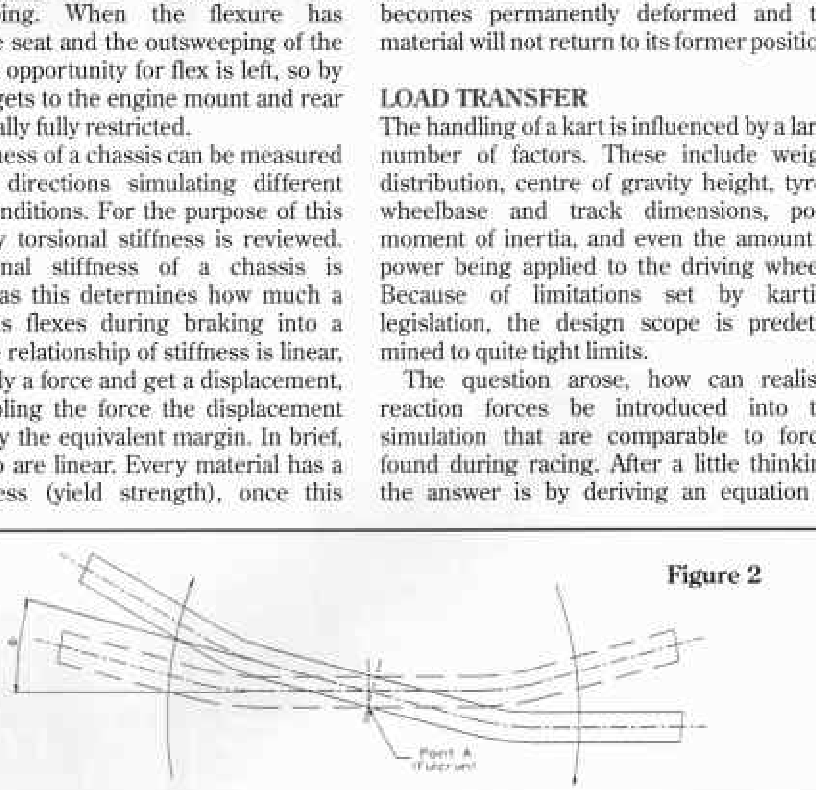

Figure 2

Chassis torsional deflection, due to moment about point A at the front cross member

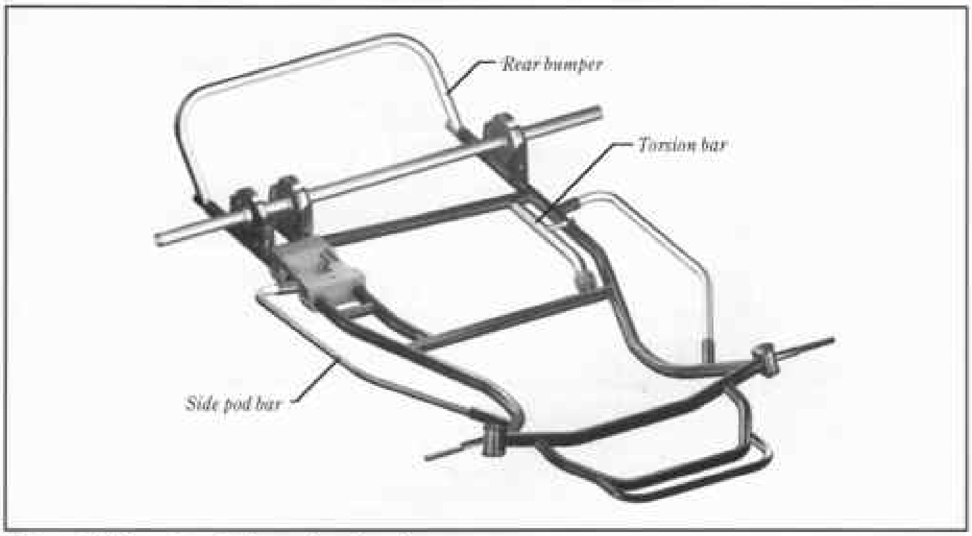

Figure 3. Structural view of a chassis

motion for deceleration of a kart. In this case only deceleration is considered, because acceleration forces are minimal in comparison to braking. By applying Newton's Laws, an expression can be derived allowing for the calculation of the reaction forces on the tyres during braking.

A little understanding is required into how weight is transferred during braking, and then turning. When a vehicle is braked, a retarding force is immediately introduced between the tyres and road. But the inertia of the vehicle introduces an equal force through the centre of gravity in the opposite direction. These two equal and opposite forces constitute an overturning couple tending to lift the rear of the vehicle. Consequently, a proportion of the total load of the vehicle is transferred from the rear to the front wheels so that the magnitude of the load transferred to the static front axle reaction is increased by a small amount, then the static rear axle reaction will be decreased by an equal amount. After braking, the kart is turned into a corner and the weight is transferred to the outer wheels, leaving minimal weight on the inner rear wheel.

After deriving an expression for the reaction forces at the front of the kart, the only missing variable for the equation is deceleration, as this is the subject of obtaining realistic data/forces for the simulation. Braking forces can be measured by using a data logging system such as that available from Pi, coupled with an inertial accelerometer. This solves the unknown, and realistic reaction forces for the vertical loading on the front tyres can be calculated for varying deceleration conditions. Otherwise, reaction forces can theoretically be calculated by approximating the coefficient of friction (grip), which is dependent on grip conditions and the weight of the driver.

TORSION ANALYSIS

The torsion analysis investigates how different components effect the torsional stiffness of the chassis. Maximum torsional deflection occurs during maximum braking/deceleration and turning into a corner. A chassis with optimal torsional stiffness is important, where the torsional effect is evident (Figure 1). This shows a kart entering a right hand corner, and due to weight transfer on the front left wheel, causes the left front to sag, and the diagonal wheel (rear right) to lift.

It is important not to just analyse the performance characteristics with respect to torsional stiffness, but also investigate that maximum stresses on the members don't exceed the material yield strength (critical stress).

Torsional stiffness is calculated from the formula $k = T/\theta$, where k is the chassis torsional stiffness ($Nmdeg^{-1}$), T is the amount of torque on the front cross member about the fulcrum (Nm), and θ is the angle of deflection of the front cross member w.r.t. equilibrium position (Figure 2).

The highest reaction forces expected over the front wheels are during maximum braking as the weight is transferred through the centre of gravity over the front wheels. After maximum braking the kart is turned into a corner with the weight still over the front wheels, therefore the outside front wheel is flexed further upwards from the additional reaction force, in comparison to the other wheels. The torsion test is a comparable situation, where the front of the kart at the front cross member is twisted relative to the rest of the chassis.

Several permutations of kart chassis adjustment are available with respect to how a chassis can be adjusted prior to racing. By using finite element, these changes can be simulated and predicted. The objective of the analysis is to show how a chassis flexes during braking and turning, and secondly that stresses are below the yield strength for each structural member.

The simulation involves analysing how the torsion bar, side pod bars and rear bumper effect the rigidity of the chassis. The first analysis begins with a flexible kart chassis set-up, and after each successive analysis a component is added to the flexible chassis. A comparison is made to observe how the chassis stiffness changes with respect to each member. The final analysis incorporates all the components as shown in Figure 3. This makes a comparison with the flexible chassis that has no torsion bars, and how the torsional stiffness has been changed.

The simulation analyses (Table 1) shows what effect certain bars have on the stiffness of the chassis. These representations of a chassis are used in certain grip conditions, where bars, loosely secured to the chassis by means of a nut and bolt assembly, are assumed not to be acting in any capacity with respect to the rigidity of the chassis. Therefore in these cases the members have negligible effect on chassis performance, and are not analysed for that case.

The first case looks at the most flexible option in kart chassis adjustment, which analyses a chassis with loose side pod bars, rear bumper and no torsion bar. The second analysis of the kart chassis is with the rear bumper firmly secured. The third case looks at the chassis with side pod bars firmly secured. The fourth case analyses the contribution the mid-mounted torsion bar has on the rigidity of the chassis. The final analysis looks at the most rigid option in kart chassis adjustment, i.e. all the bars previously mentioned are combined and analysed.

On analysing all chassis configurations, the least torsionally stiff chassis was the flexible configured chassis (case 1), as expected, with the rigid chassis (case 5) being the most torsionally stiff. The rear bumper had negligible effect with regards to the stiffness of the chassis, while the torsion bar increased torsional stiffness by 3.4% over the flexible chassis.

The most influential components were the side pod bars, these increased the stiffness by 15.9%. Figure 4 (case 5) is a deformation plot of the displacement in the vertical direction. As the twist moves back down the frame, members that have different main functions can be used to impart more and more restraint to the flex continuing. The placing of the cross member half way down the chassis drastically alters how the chassis flexes. The cross member in the middle of the chassis provides the first restriction to

Comparison of torsional stiffness for different chassis configurations (figures are percentage increases over the flexible chassis)

Case		%
1	Flexible chassis	0
2	Rear bumper	0.8
3	Side pod bar	15.9
4	Torsion bar	3.4
5	Rigid chassis	19.4

Table 1

FIRST AMERICAN VINTAGE KART SHOW


Roger Biss and an early Fox kart *Karting magazine library phot*

The inaugural Wayne May Memorial Vintage Kart Show, named after the Woodbridge Kart Club President who recently died tragically in a boating accident, was held over the weekend of 25/26th July at Summit Point Raceway in West Virginia USA and attracted a wonderful array of classic American karting machinery with pieces of Italian engine work thrown in for good measure.

Organised by long time south Jersey karter Jack Foster the show had a restored 1960 example of a Homelite chassis with 1962 Homelite KL100 engine, Margay sprint and laydown machines from the middle '70s era as well as a model of a Fox kart from early 1960, albeit the one which did not have the attractive satellite seat as it was referred to in the advertising literature back then.

There was also a nice example of the Ohio constructed SAE kart 1963 vintage powered by twin Mac 7s and, awaiting restoration, a 1960 Blitz model known as the Thunderblitz so favoured by the people from Long Island where it was manufactured. A Texas manufactured Chaparral enduro kart painted a beautiful candy apple green with brightly polished aluminium long range fuel tanks also attracted a lot of attention.

Also on show was one of Don Fairman's Blackhawks from around the late '70s in almost new condition as well as a variety of engines from McCulloch, West Bend and IAME. The IAME marque was represented by the B Bomb model, the 135cc version of the 100cc Komet 88 and the Parilla SS20. Along with the engines were a couple of Margay gearboxes. These devices allowed quick changes of the drive ratios by changing cogs in the pits rather than by using a lever while the kart was in motion which of course was banned. They also did away with chains.

Magazines from the early days together with newspaper clippings and persona photos adorned the display tables reminding all just how far the sport of Karting has travelled. Besides the old literature was the latest coloured downloads from the Vintage Kart web pages (www.vintagekarts.com) illustrating amongst many a Go Kart 800, a Dart A-Bone, a Bug Sprint, and one of Art's yellow Carettas, all beautifully restored.

An announcement via the web from Richard Peck who along with his father constructed Hornet karts in Texas back in the early '60s about his planned book detailing his involvement with those early karting days was noted.

Interestingly beside the Blitz chassis display was a newspaper piece about grandiose houses in the Long Island part of New York which showed a picture dated 1922 of a small boy on what appeared to be a motorised type coaster with four smal spoked bicycle wheels and a steering wheel This predates by 15 years the article in the June 1997 edition of National Kart News which reported on the 1937 Gilbert kart.

Nevertheless, most old time karting aficionados still consider Art Ingels to be the inventor of karting and it was great to see that karting's roots have not been forgotten, especially by people like Jack Foster, who owned 11 of the karts on display and probably as many of the engines, and www.vintagekarts.com webmaster Bob DiNozzi.

Now which direction for Grants Pass to find Duffy?

Frank Wein

OPTIMISATION continued

further flex, as there is little deformation past this point.

CONCLUSION

On the basis of the results the most influential components with regards to increasing the torsional stiffness of the chassis were the side pod bars. The material selected for each member should be on the basis of having a comparable yield strength with respect to the maximum stress for that member.

Designing a chassis using this design philosophy, i.e. CAD, allows an accurate comparison of how members change the characteristics of the kart under different dynamic conditions. This is important when designing and developing any mechanical component for performance, because developing for optimum performance at the design stage (as with any motor sport) is the objective.

I can be contacted by email (aie@alphalink.com.au) if further information is required.

Andrew Innes

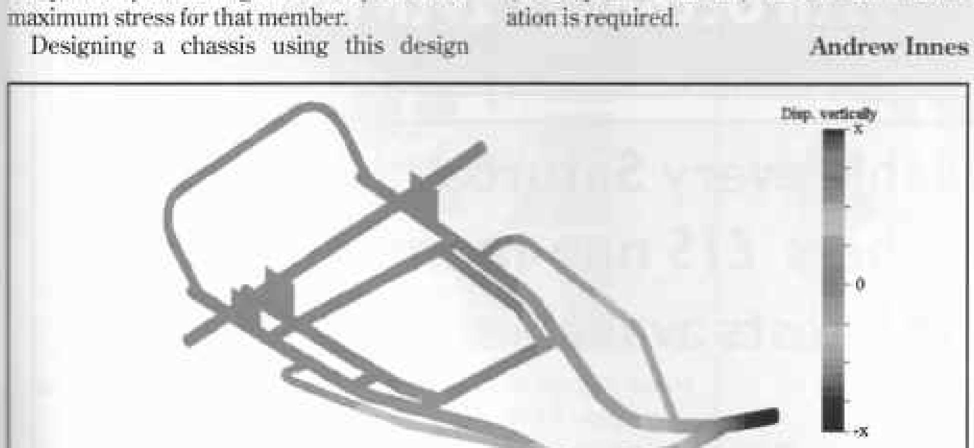

Figure 4. Chassis deflection in the vertical direction due to a force applied in the upwards direction on the right hand stub axle and in the opposite direction on the other stub axle. This creates a moment/torque about the centre of the front cross member A